SSFP cardiac cine imaging with high blood - myocardium contrast at 3T

B. A. Jung[1], D. Paul[1], J. Hennig[1]

[1]Department of Diagnostic Radiology / Section of MR physics, University Hospital, Freiburg, Germany

Introduction

Magnetic resonance imaging at 3 Tesla is often restricted by a relatively high rf-power deposition. The maximum flip angle in cine imaging for cardiac function with steady state free precession (SSFP) sequences is limited by the specific absorption rate (SAR) because of the continuous application of rf pulses with short repetition times (TR). If the flip angle is decreased to limit the SAR, then the SNR and the contrast between the blood pool and the myocardium are also reduced. Therefore, automatic or manual segmentation of the myocardial contours becomes more difficult and the quality in functional diagnosis in cardiac imaging may be affected. The first method to reduce the SAR at higher field strength in TSE sequences by using variable flip angle schemes was proposed in [1], in imaging with SSFP sequences it was introduced in [2]. Similarly we implemented a sequence which maintains a high SNR and contrast between blood and myocardium with a lower SAR by using variable flip angles along the phase encoding direction. Since the center of k-space determines the contrast of the image, an acquisition of these phase encoding lines with a high flip angle leads to an increased contrast between blood and myocardium.

Methods

Different flip angle schemes were implemented with the highest rf-power deposition allowed for scanning of human subjects. 16 phase encoding lines were acquired per cardiac phase, so that 12 heartbeats were necessary to fill the k-space matrix of 192 lines. Two representative flip angle schemes are 30°; 30°; 30°; 40°; 50°; 60°; 60°; 50°; 40°; 30°; 30°; 30° (mean=40°) and 35°; 35°; 35°; 35°; 45°; 70°; 70°; 45°; 35°; 35°; 35°; 35° (mean=42°, allowed maximum); a linear phase encoding scheme was used over the heart cycles. The different phases during one heart cycle were acquired with identical flip-angles in order to obtain identical contrast behavior for all phases. After the last excitation of one heart cycle an additional "α-half"-step $\alpha_{half} = (\alpha_n + \alpha_{n+1})/2$ was inserted to produce a smoother transition to the higher (or lower) flip angle in the next heart cycle and, therefore, to avoid signal oscillations. The period at the end of the heart cycle before the detection of the next R-wave (typically about 10 % of the RR-interval) can be used to play out this additional rf-pulse. Fig.1 shows the simulation of the on-resonance magnetization behaviour with and without the additional α-half-step. A smooth transition without signal oscillations can be seen between the two flip-angle values of the different heartbeats (Fig 1a). Therefore, it is not necessary to perform a longer flip angle variation with smaller increments to reach the steady state of the flip angle for the next heart cycle.

Cardiac cine imaging was performed on healthy volunteers on a Trio 3T (Siemens Medical Solutions, Erlangen, Germany) with gradients supporting 40 mT/m amplitude and 200 T/m/s slew rate. SSFP-imaging was performed with a TR of 3.5 ms and a temporal re solution of 56 ms. One slice in a short axis view was acquired in a breathhold period of 12 heartbeats and with continuous rf-pulsing prior to the detection of the next R-wave. Additional imaging parameters were: FoV (262 x 350 cm, matrix 192 x 256, slice thickness 8 mm).

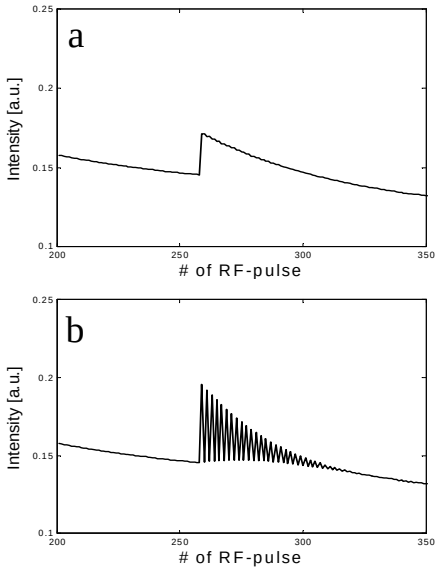

Fig. 1: Simulations with (a) and without (b) α-half-step (TR=3.5 ms, T1/T2=800/70 ms, $\alpha 1/\alpha 2$=50°/60°, 256 pulses before step to next flip-angle).

Results

Fig. 2 a shows a diastolic and a systolic image out of 16 acquired with the conventional sequence. The maximum allowed flip angle was 42° (the typical range of the maximum flip angle given by the SAR limitation with SSFP cardiac cine imaging in patients at 3 T is between 30° and 45°, at 1.5 T between 55° and 70°). Fig. 2 b shows the identical two phases with the second flip angle scheme introduced above and a maximum flip angle of 70° at the center of k-space. The SNR of the two different regions of interest in the blood pool and in the myocardium, ROI 1 and ROI 2 (see Fig.1), respectively, for the conventional and the variable flip angle sequence is listed in Table 1, also the resulting CNR between blood and myocardium.

Sequence type	SNR ROI 1 (a.u.)	SNR ROI 2 (a.u.)	CNR
Conventional sequence	182.8	107.6	1.7
Variable flip angle scheme 1	271.6	92.6	2.9
Variable flip angle scheme 2	301.9	94.2	3.2

Table 1: SNR and CNR for blood the two ROIs with the different sequences.

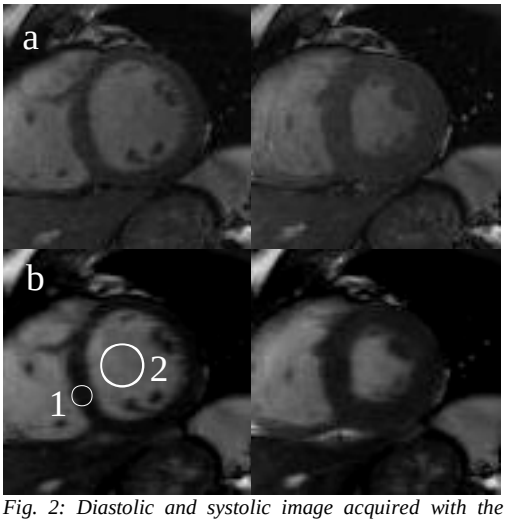

Fig. 2: Diastolic and systolic image acquired with the conventional sequence (a) and of the sequence with a variable flip angle scheme 2 (b) both with same scaling and the ROIs for the calculation of CNR.

Discussion

This work demonstrated that higher SNR and CNR between blood and myocardium is achievable in SSFP cardiac cine imaging at 3 T with variable flip angle schemes while staying within the range of allowable rf-power depositions. The presented acquisition scheme is easy to implement while there are also other possible flip angle variations. The scheme influences not only the image contrast but also the image sharpness since flip angle variations also slightly affect the in-plane resolution due to a blurring of the point-spread function [2]. In addition, flip angle differences between the segments can introduce ringing artifacts from discrete weighting steps in k-space. However, such artifacts were not observed in the in-vivo scans.

References

[1] Hennig et.al. *MRM*, 46:6-12, 2001.
[2] Schaeffter et.al. *Proceedings of ISMRM*, p.2351, 2002.
[3] Hennig et.al. *MRM*, 48:801-809, 2002.